A MULTI-PROXY APPROACH TO PALAEOCLIMATIC STUDIES OF LAKE SEDIMENTS FROM THIMMANNANAYAKANAKERE, SOUTHERN KARNATAKA, INDIA

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By

ANISH KUMAR WARRIER

(CSIR-SRF)

DEPARTMENT OF MARINE GEOLOGY
MANGALORE UNIVERSITY
MANGALAGANGOTHRI – 574199
INDIA

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Name of the Candidate	:	ANISH KUMAR WARRIER
Name of the Guide	:	Prof. R SHANKAR
Date of registration	:	7th December 2005
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INTRODUCTION

Climate may be defined as the general weather conditions in an area over a long period. Life on the Earth is influenced and supported by two important components of climate, i.e., temperature and rainfall. The Earth's climate has witnessed several changes on all temporal and spatial scales as a result of forcing factors like variations in the orbital parameters of the earth, solar variability and volcanic eruptions (Bradley, 1999). Paleoclimatalogy is a diverse and rapidly expanding science that encompasses a wide variety of archives (for eg., marine and lacustrine sediments, tree-rings, ice-cores, corals, speleothems etc.) that are capable of providing information on past climatic conditions. Natural archives present in our environment provide a way to reconstruct past climatic changes, because they incorporate, in some way, climate-related phenomena into their biological, chemical or physical structure (Alverson et al., 2002). With recent concerns about anthropogenically driven global warming, the need for reliable long-term paleoclimatic data is widely recognised by individuals, government agencies, and international organisations because these records provide the background information against which recent changes can be assessed (Smol and Cumming, 2000). Only with this "paleo" perspective can one understand natural climatic variability and change and so increase the ability to predict and prepare for future climatic conditions.

Instrumental records of climate variability as well as climate forcing factors have a great potential to quantitatively document environmental changes as and when they occur. However, these accurate records date back to several decades to a few centuries. To know the climatic conditions farther back in time, indirect indicators of climate variability are made use of. These indicators are known as proxies, which may be defined as properties that are imprinted in sediments and can be useful in reconstructing the past climate. Some important proxies are magnetic properties, stable isotopes of oxygen and carbon, pollen, particle size, geochemical and clay mineralogical properties. Lakes are one of the best archives to study paleoclimatic variations as they are more sensitive, when compared to the oceans, to climatic and environmental changes due to their smaller size and higher sedimentation rates. Innumerable investigations on lake sediments have been carried out worldwide to decipher paleoclimate / paleoenvironmental conditions on different temporal scales (Cohen, 2003; Fritz, 2008; Dearing et al., 2008; Stevens et al., 2006; Asikainen et al., 2007; Lucchini et al., 2003; Stager et al., 2005). In India, a few lakes from northern India, especially Rajasthan (Singh et al., 1974, 1990; Enzel et al., 1999; Prasad et al., 1997; Roy et al., 2009) and the Himalaya (Juyal et al., 2004; Wűnnemann et al., 2008; Bhattacharyya, 1989), have been used to infer paleoclimate during the Holocene.

It is clear from the foregoing that whereas studies have been made on lake sediments from Northern India, no such work has been carried out for Southern Indian lakes, especially those of Karnataka. Over the past few years, paleomonsoon rainfall variability have been reconstructed using wind-strength related proxies like lithogenic grain size, upwelling- and productivity-related proxies like *G. bulloides* abundance, $\delta^{15}N$ and organic carbon content and monsoonal precipitation-related proxies like sea surface salinity. However, these proxies give an *indirect* measure of the rainfall. In this study, an attempt has been made to use magnetic susceptibility as a *direct* measure of past monsoonal rainfall variations in the *tropical* regions.

Objectives of this study:

The main objectives of this investigation are:

- To explore the possibility of using magnetic parameters as a proxy for paleorainfall in tropical regions;
- To determine variations in climate, principally rainfall, of a tropical area during the past few thousand years using a multi-proxy approach;
- To examine if solar activity controls the variations in southwest monsoon;
- To understand pedogenesis, magnetic enhancement of top-soil, if any, in a tropical environment and the transport of magnetic minerals from the catchment to lake environment using environmental magnetism;
- To determine variations in chemical weathering intensity during the past few thousand years using inorganic geochemistry as a tool; and
- To document the effects of anthropogenic activities like agriculture and deforestation, if any, on the paleoclimate data obtained.

The present investigation has been discussed in eight chapters. A brief account of the contents dealt with in each chapter is given below.

CHAPTER 1: INTRODUCTION

This chapter provides a brief introduction to paleoclimate and how paleoclimatic studies may be carried out by using different paleoarchives and proxies. This is followed by a general review of literature of the work done on lake sediments from different parts of world as well as from India. Details of the study area, climate, vegetation and geology are also discussed in this chapter.

CHAPTER 2: SAMPLING AND METHODOLOGY

In this chapter, details about sample collection and different methodologies (radiocarbon dating, environmental magnetism, citrate-bicarbonate-dithionite treatment, inorganic geochemistry, particle size analysis, spectral and wavelet analyses) adopted in this work are discussed.

CHAPTER 3: ENVIRONMENTAL MAGNETIC RECONSTRUCTION OF PALEORAINFALL FOR THE PAST 3,700 YEARS

In this chapter, the rock magnetic properties of sediments from Thimmannanayakanakere are discussed (Fig. 1). An attempt is made to correlate the magnetic properties of TK sediments with instrumental rainfall data (Fig. 2). A good positive correlation is documented between magnetic susceptibility and instrumental rainfall data for the past 100 years. This deduction was made after discounting the possibilities of the presence of bacterial magnetosomes, greigite and anthropogenic magnetite, and discounting the possibility of dissolution of magnetic minerals. It is shown that the magnetic minerals in the TK sediments were principally derived from the catchment. Historical records of a high-rainfall period (1741 AD) and a drought (1876 AD) are well seen in the magnetic susceptibility record and other rock magnetic parameters. The paleorainfall data obtained from this study show similarities with other proxy records from India. Rock magnetic properties of a soil profile and a few surficial soil samples from the TK catchment were also carried out and their relationship with the TK sediments are discussed in this chapter.

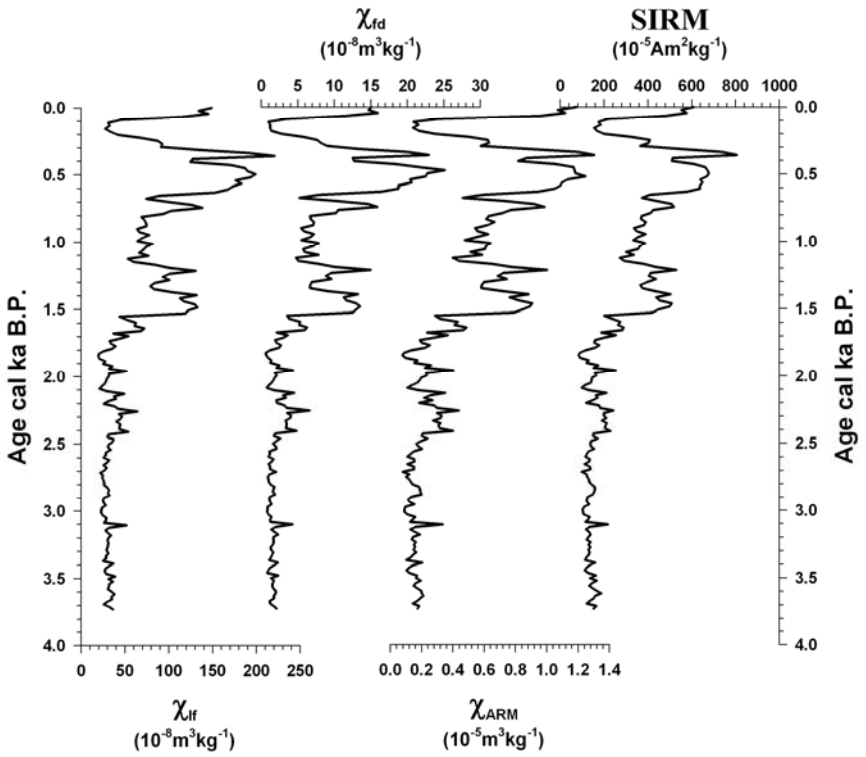

Fig. 1 Rock magnetic parameters for Thimmannanayakanakere sediments.

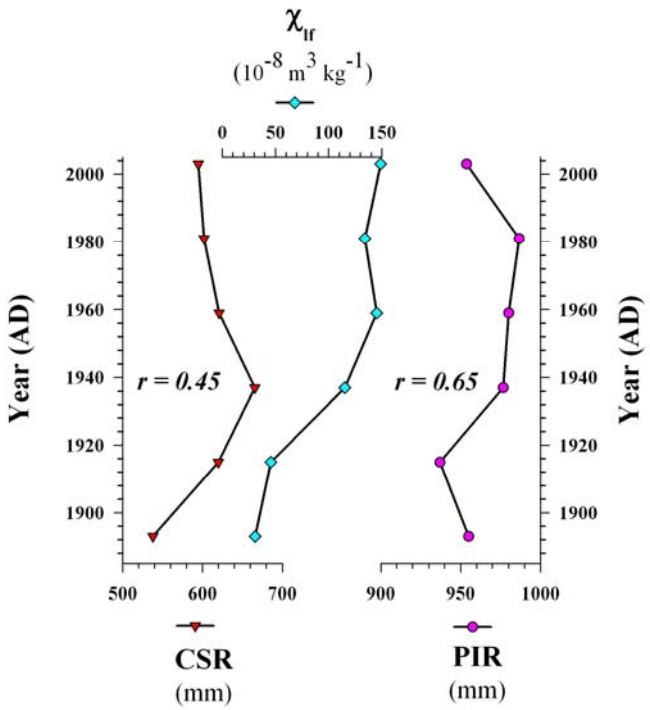

Fig. 2 Correlation of TK susceptibility with Chitradurga Station (CSR) instrumental rainfall data (a); and Peninsular India rainfall (PIR) data (b) for the last 100 years.

CHAPTER 4: PRESENCE OF PEDOGENIC MAGNETITE IN TK SEDIMENTS – RESULTS OF CBD ANALYSIS

In this chapter, results of citrate-carbonate-dithionite (CBD) treatment on selected samples of TK sediments are discussed. The CBD technique is useful in dissolving ultra-fine grained pedogenic magnetite / maghemite. During pedogenesis, ultrafine magnetite (consisting mainly of superparamagnetic (SP) grains) forms as a result of the weathering of weakly magnetic iron-bearing minerals and production of ferrihydrite as an intermediate phase (Machac et al., 2007). Temperature and rainfall are the two main factors governing the production of pedogenic magnetite. The CBD treatment data for selected samples suggest the presence of pedogenic magnetite in TK sediments (Fig. 3). A positive correlation is also documented between pedogenic χlf and instrumental rainfall data. Being located in the tropics, temperature is generally constant; hence, rainfall seems to be the dominant factor in the production of pedogenic magnetite in the TK catchment, which is reflected by its presence in TK sediments.

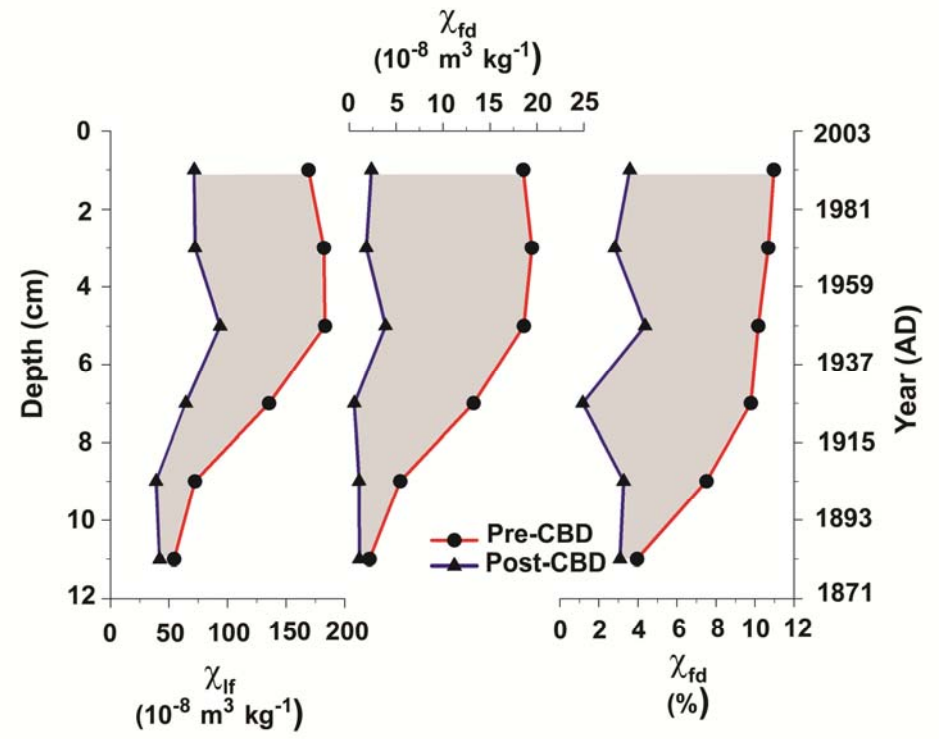

Fig. 3 Pre- and post-CBD χ_{lf}, χ_{fd}, and χ_{fd} (%) data for TK sediment samples. Note the sharp decrease in magnetic parameters after CBD treatment, suggesting the presence of ultra-fine grained pedogenic magnetite.

CHAPTER 5: A 3700 YEAR GEOCHEMICAL RECORD OF SEDIMENTS FROM THIMMANNANAYAKANAKERE

In this chapter, elemental data of TK sediments using inductively coupled plasma atomic emission spectroscopy (ICP-AES) are presented. Metal/Al ratios (Fe/Al, Ti/Al, Na/Al, Mn/Al, Pb/Al, Zn/Al, Cu/Al, K/Al, Ca/Al, Mg/Al and Sr/Al) are positively correlated with χ_{lf}, suggesting that the TK sediments have been derived mainly from the catchment. In particular, Ti/Al, K/Al and K/Na ratios (Fig. 4) which are considered good indicators of chemical weathering intensity (CWI), start increasing from ~2 cal. ka B.P. onwards, corresponding to increasing χ_{lf} from this time. Principal component analysis (PCA) was carried out on the geochemical data and a few magnetic parameters (χ_{lf} and χ_{fd}). Results of PCA suggest the presence of three controlling factors: "terrigenous", "pedogenic (= rainfall)" and "carbonate" (Fig. 5). Based on the data obtained above, a schematic model is presented to explain pedogenesis, chemical weathering intensity and carbonate precipitation, which are all related to rainfall in the TK catchment.

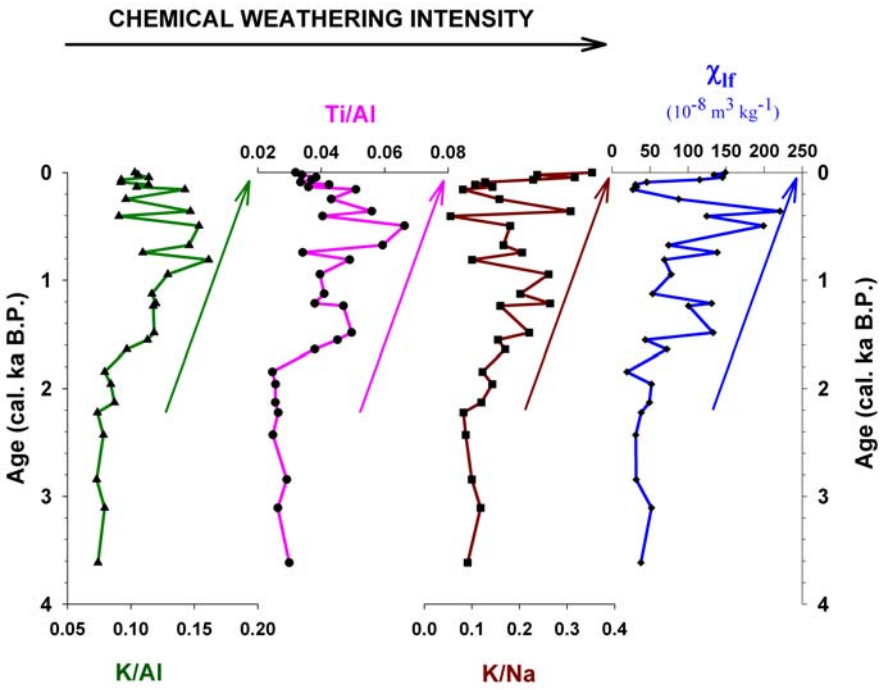

Fig. 4 Profiles of χ_{lf}, Fe/Al, Ti/Al, K/Na, K/Al for TK sediments. Chemical weathering intensity ratios like Fe/Al, Ti/Al, K/Al and K/Na suggest an increase in the intensity of rainfall from 2 cal. ka B.P. onwards.

CHAPTER 6: PALEOCLIMATE RECORD OF TK SEDIMENTS: PARTICLE SIZE DISTRIBUTION AS A PROXY

Particle size is closely linked to turbulence, wave energy, and proximity to shoreline, increased particle size generally corresponding to higher energy conditions of sediment production or transport and *vice versa*. Particle-size fluctuations through time, particularly of sand size, may reflect low-level lake stands related to periods of drier and warmer climate and *vice versa* (Alin and Cohen, 2003). In this chapter, the data obtained from particle-size analysis using the traditional sieving and pipette methods (Carver, 1971) are discussed. The bulk sediment was divided into five size fractions i.e., sand, coarse silt, medium silt, fine silt and clay fractions. The data obtained suggest that magnetic minerals in the TK sediments reside mainly in the fine silt fraction (r = 0.65; n = 31; significant at the 1 % level). The data also reflect changes in the processes and energy of sediment transport.

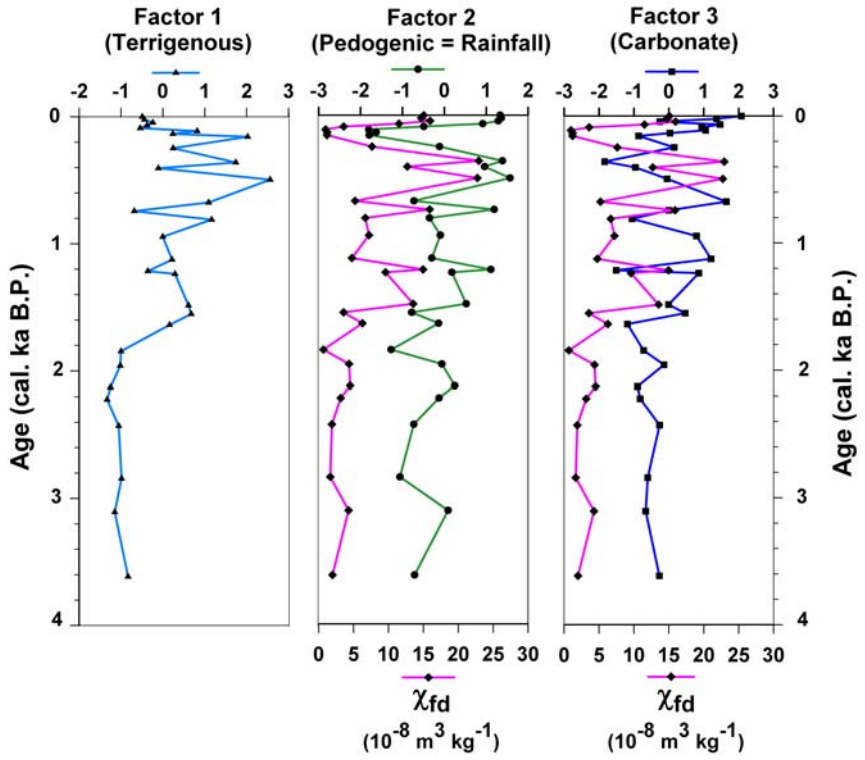

Fig. 5 Factors 1, 2 and 3 scores (a, b and c) plotted against age. Also plotted is χ_{fd} in (b) and (c) for comparison.

CHAPTER 7: EVIDENCE OF SOLAR FORCING ON THE SOUTHWEST MONSOON: RESULTS OF SPECTRAL AND WAVELET ANALYSES

The results of spectral and wavelet analyses of the TK χ_{lf} data are discussed in this chapter. The raw χ_{lf} data revealed statistically significant periodicities of 906, 232, 147, 128, 96, 61, 54 and 44 years (Fig. 6). The raw χ_{lf} data were treated with Savgol filters (Press et al., 1992) to remove the low-frequency components present in the data. This step was performed to understand the presence of high-frequency components as they are usually suppressed by the low-frequency components (Yadava and Ramesh, 2007). The additional periodicities obtained apart from the ones discussed above are 106, 84, 73 and 64 years. The 232-year periodicity may be related to the 210-year Suess cycle also known as the De Vries cycle. A 205-yr statistically significant periodicity is also documented in the spectral results of the reconstructed sunspot data. This suggests a possible link between solar variability and the SW monsoon. The 85-year cycle documented in the TK χ_{lf} record may correspond to the 88-year Gleissberg cycle of solar origin. Agnihotri et al. (2002) reported a ~ 89-year periodicity in the C_{org} record from the Eastern Arabian Sea sediments. This cycle is also seen in the $\delta^{14}C$ record which has been ascribed to solar variability (Stuiver and Braziunas, 1993). The TK χ_{lf} record exhibits a 61-year periodicity significant at the 5 % level. This cycle is believed to be an important feature of the recent variability of the Indian monsoon (Sinha et al., 2005). Sontakke et al. (1993) documented a 60-year cycle in instrumental rainfall records. The 60-year cycle is considered to be of solar origin influencing the Indian summer monsoon (Agnihotri et al., 2002). Spectral analysis was also performed on the reconstructed sunspot number data (Solanki et al., 2004). The periodograms for the reconstructed sunspot number data also reveal a statistically significant 61-year periodicity.

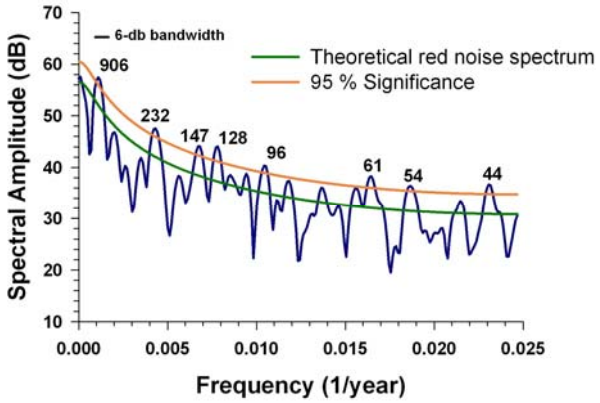

Fig. 6 Spectral analysis results for TK magnetic susceptibility record.

Whereas the more traditional spectral analysis helps determine the dominant modes of climatic variability of the paleoclimatic proxy records (Ghil et al., 2002), wavelet analysis transforms a one-dimensional frequency spectrum into a two-dimensional time-frequency image (Lau and Weng, 1995; Torrence and Compo, 1998). This enables one to understand frequency and amplitude modulation of climatic oscillations over time, a common objective in climate dynamics. Wavelet transform analysis of the regularly spaced time series of TK magnetic susceptibility was carried out using the interactive software available at http://paos.colorado.edu/research/wavelets. The wavelet transform analysis confirms the results of spectral analysis (Fig. 7). The 915-year cycle is continuous throughout the past 3000 cal. years B.P., reaching its maximum power from 2200 cal. years B.P. onwards. The 230-year Suess cycle is seen around 1800 cal. years B.P. and is absent prior to 2000 cal. years B.P. Smaller cycles like the 150, 125 year ones are seen for a short period between 1700 and 1500 cal. years B.P. and appear again from 1000 cal. years B.P. These cycles too, like the 235-year Suess cycle, are absent prior to 2000 cal. years B.P. All these data suggest the solar forcing of the southwest monsoon.

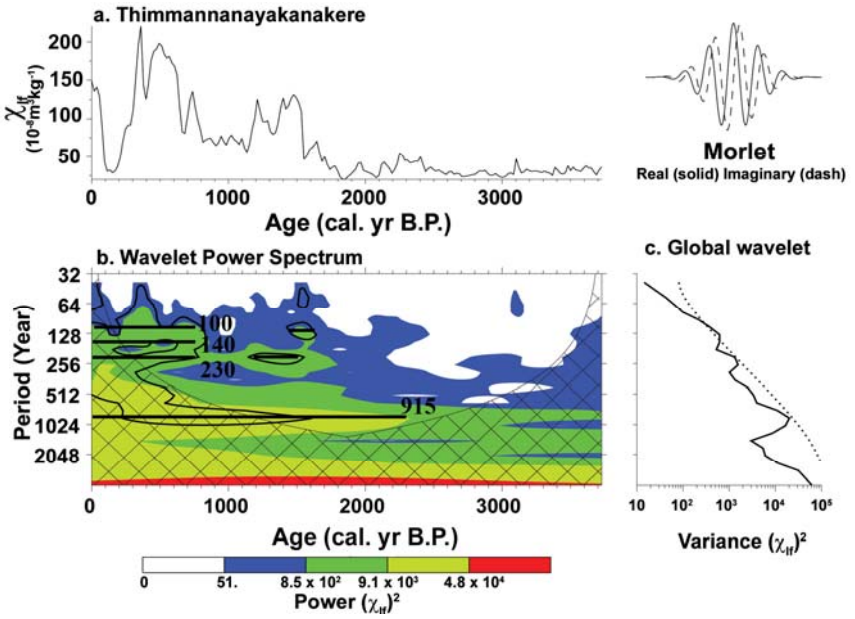

Fig. 7 (a) TK magnetic susceptibility time series curve. (b) The wavelet power spectrum. The contour levels are chosen so that 75%, 50%, 25%, and 5% of the wavelet power is above each level, respectively. Black contour is the 5% significance level, using a red-noise background spectrum. (c) The global wavelet power spectrum (black line). The dashed line is the significance for the global wavelet spectrum, assuming the same significance level and background spectrum as in (b).

CHAPTER 8: SUMMARY AND CONCLUSIONS

In this chapter, the major conclusions drawn from the work carried out are highlighted and the scope for future work is discussed.

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- **Anish K Warrier** and R Shankar (2009) *Geochemical evidence for the use of magnetic susceptibility as a paleorainfall proxy in the tropics*. **Chemical Geology, v. 365 (3-4), pp. 553-562.**

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- R. Shankar, C. N. Prabhu, **A. K. Warrier**, G. T. Vijay Kumar, and B. Sekar (2006) *A Multi-decadal Rock Magnetic Record of Indian Monsoon During the Past 3,700 Years from a Tropical Indian Tank.* Spl. Issue on Indian Monsoon, **Jour. Geol. Soc. India**, v. 68, pp. 447-459.

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Anish Kumar Warrier
Ph D Candidate

R Shankar
Research Supervisor